Peatland development and paleoclimate records from the Holocene peat archive in the foothills of the Eastern Sayan Mountains

A B Rodionova, A V Grenaderova

Department of Ecology and Environmental Studies, Institute of Ecology and Geography, Siberian Federal University, 79 Svobodny pr., 660041 Krasnoyarsk, Russia

rodionovaab@yandex.ru, grenaderova-anna@mail.ru

Abstract. Plant macrofossils data were used to identify the successive peatland communities during the last 3500 years in the floodplain of the Mana River (foothills of the Eastern Sayan Mountains). The reconstruction of the peatland development indicated that the peatland in the Mana River basin formed about 3500 years ago. The peatland formed as a result of overgrowing floodplain and water logging of terrace lows. The authors observed three successive changes: birch forest with sedge and hypnum mosses in the second half of the Subboreal period, wood-marsh plant association at the start of the Middle Subatlantic period (1600 years BP), the herb-wort phytocoenosis with inclusions of mezoeutrophycal plant species have been growing since the Late Subboreal period (950 years BP).

1. Introduction

Peatlands are an important natural archive for past climatic changes, primarily due to their sensitivity to changes in the water balance and the dating possibilities of peat sediments. The climatic changes throughout the Holocene have been reconstructed from peat, using a wide array of biological and other proxies. Many different proxy-indicators may be derived from peat cores [2].

Peat-based climatic and environmental reconstructions are currently available from many sites in Yenisei Siberia, mainly for its northern territories. The purpose of this research is to study some features of peatland development and environmental reconstructions from the Holocene period in the south part of Yenisei Siberia (foothills of the Eastern Sayan Mountains).

The study area was the peatland "Narva" in the floodplain of the Mana River. The main method of the research was macrofossils analysis of peat. This analysis can be used to reconstruct the development of the local vegetation and surface wetness on peatlands, and thus to elucidate successional processes. To interpret these proxies by macrofossil analysis, the current botanical composition of the bog and the ecological behavior of different plant species were used. The analysis of plant macrofossils in the peat, based on the study of the flora and vegetation in a particular place over a period of time, has allowed us to reconstruct the environmental changes that have occurred since the Late Glacial Period. The macrofossil types were identified with Kac and Kac Atlas [8]. The reconstruction of the bog surface wetness was performed on the basis of the analysis of plant macrofossils. After that, we used the ecological scales of moisture and reconstructed surface wetness for the entire period of the peatland formation.

2. Materials and methods

The Narva peatland is located at the foothills of the Eastern Sayan Mountains, Yenisei Siberia, Russia, at a distance of 20 km of the southern boundary of Kansk forest-steppe. The peatland has a width of 2 km, a length of about 6 km, and is extended along the right bank of the Mana River (Yenisei's inflow). The ground water level has been recorded at around 20 cm. The surface vegetation mostly comprises eutrophic (bog) assemblages. The present vegetation is a mixed herb-moss forest. The shrub layer includes *Oxycoccus microcarpus* Turcz. The herbal layer consist of sedges (such as rhizomatous species of sedge (*Carex cespitosa* L., *C. appropinquata* L.) and *Equisetum palustre* L. The ground layer is largely dominated by the Hypnales (*Tomentypnum nitens* Hedw., *Aulacomnium palustre* Hedw.) and Sphagnales (*Sphagnum warnstorfii* Russ).

A cross-section was laid in the peatland for the watershed part toward the shore line of the Mana River. The cross-section length was 550 m. The drilling sites were chosen in places with different phytocenoses. We carried out drilling of peat cores in three locations. The altitude at point 1 was 380 meters. The difference in altitude from point 1 to the riverbed was 1 m.

Three peat cores (Narva 1, Narva 2, Narva 3) were collected in July 2011 from lawn microforms with a Box core. The collected cores were wrapped in plastic gutters until required for analysis. The types of sediments were identified in the laboratory.

The maximum thickness of peat deposits (1.50 m) was recorded for a hillside (20 meters apart from the base of the Mana River first terrace). The peat deposit consisted of eutrophical peat types: wort, sedge-wort, wood-grass and horsetail.

The peat samples (5 cm^3) from cores Narva 1, Narva 2, Narva 3 were taken at 5 cm increments. They were heated in 5% KOH solution and rinsed with distilled water through a 0.5 cm sieve. The analysis was carried out by counting macrofossil pieces, using available identification keys [8, 14] and by estimating peat components as volume percentages of the total sample. The volume percentages of different remained vegetation and Sphagnum section were estimated in step of 5%. The identification of Sphagnum to species level was performed separately based on stem leaves using specialized keys [7].

The multi-proxy research of detailed macrofossil analysis and peat stratigraphical studies provided temporal precision and increased understanding of climate changes on local and regional scales [3].

Feurdean et al. [5] suggested using combined macrofossil and pollen analysis, which assisted in understanding of the differences between local and regional flora. The lack of macrofossils from leafed trees, which were plenty in the surrounding vegetation according to the pollen data, indicated that these trees were not growing on the peatland or around its banks.

After macrofossils analysis we used the ecological scales of moisture by Ramensky and Ellenberg [4, 12] and reconstructed the surface wetness for the entire period of the bog formation based on the plant degree of moisture-loving. The ecological scale of moisture range by Ramensky has 120 points. The Ellenberg ecological scale has 12 points.

The ecological scales were about the methods of assessing a plant habitat and determining a plant community position along the gradients of ecological factors.

Ramensky placed each species on a 120-point ordinal scale according to its distribution with respect to moisture. The characteristics of the moisture regime (e.g. groundwater level, soil moisture content, and soil moisture deficit) were used in determining these classes. Ramensky's indicator values were used to estimate the value of any of these environmental factors at a particular site by averaging the indicator values for this factor of all species present. Plants often reflect temporally integrated environmental conditions and they were therefore particularly useful indicators when values averaged over time were needed. Identify the value of an environmental factor in the past the only possible approach may be to relate it to historical vegetation data. The Ramensky scale offered 5 gradations (Table 1).

Table 1 Gradations which accounted for projective cover.

m (abundant)	**more than 8%**

c (rich)	2.5-8%
n (moderate)	0.3-2.5%
p (low)	0.1-0.2%
a (sporadic)	<0.1%

The European scale of moisture was not comparable to Ramensky scale, due to the diversity of natural areas and the range of geographical regions. The Ramensky scale covers tundra, forest- tundra, taiga, coniferous and broad-leaved forests, forest-steppe, steppe, desert. The entire 120-point scale was divided into 12 stages.

Each stage included a total of 6 to 13 points, only the first (the desert) was 17 points. The other 5 stages (starting with 77 points) were specific for intrazonal habitats and communities (peatlands, water and riparian vegetation).

Table 2 Ellenberg scale & Ramensky scale points.

Ellenberg scale	Ramensky scale
1 on extremely dry soils, e.g. bare rocks	1-17 desert
2 in-between 1 and 3	18-30 semidesert
3 on dry soils	31-39 dry steppe
4 in-between 3 and 5	40-46 middle steppe
5 on fresh soils, i.e. under intermediate conditions	47-52 wet steppe
6 in-between 5 and 7	53-63 dry and fresh grassland and forest
7 on moist soils which do not dry out	64-76 wet grassland
8 in-between 7 and 9	77-88 moist grassland
9 on wet, often not well aerated soils	89-93 marsh-grassland
10 on frequently inundated soils	94-103 peatland
11 water plant with leaves mostly in contact with the open air	104-109 sudd
12, mostly totally immersed in water	110-120 underwater plant

We assessed humidity conditions during the whole period of peat accumulation and marked different phases in the development of peatland, and described their vegetation. Radiocarbon dating was carried out at Sobolev Institute of Geology and Mineralogy, Russian Academy of Sciences, Novosibirsk. Dates had been calibrated using the probability method and the bidecadal data set in the computer program CALIB version 7.1.

3. Results and discussion

Stratigraphy, radiocarbon dating and plant macrofossils were used to reconstruct the development and ecology of a small raised peatland because a peatland with a small area was most sensitive to climate change [9]. The Narva peatland area was 1020 ha, which was relatively small.

The peat layers were underlayed by sediments of the floodplain facies – sandy loam, which dated back to the middle Subboreal time (radiocarbon age was 3405 ± 167 cal. years BP in the interval 1.75-1.85 m). The floodplain facies consisted of oxbow loams which included macrofossils of sedge fabrics, horsetail, bark of spruce and birch, isolated green moss macrofossils.

The birch forest with sedge, spruce and hypnum moss was developed in a high floodplain of the Mana River in the second half of the Subboreal period. Shallow bodies of water were located along the river and at some distance from it and that resulted in the general decrease in the water content and started its overgrowing. The process of peat accumulation was intensified (Figure 2) in the warm conditions of the late Subboreal period. The increased degree of decomposition and low peat ash gave evidence about the overall decline of moisture conditions and rising of the river water level. These conditions led to stable conditions of the hydrological regime.

At the beginning of Subatlantic period (Figure 2) *Picea obovata* Ledeb. dominated in the tree layer of paleo plant formation with *Equisetum palustre* and then *Carex lasiosarpa* L. dominating in the herbal layer. The spruce forest with sedge and hypnum moss (*Tomentypnum nitens* and *Aulacomnium palustre*) grew under these conditions.

The wood-marsh plant formations were changed through herb-wort in 1600 BP. The herbal layer consisted of *Equisetum palustre*, *Calamagrostis lanceolata* L., *Eriophorum vaginatum* L., *Comarum palustre* L., *Menyanthes trifoliata* L., and sedges: *Carex cespitosa*, *C. lasiosarpa* , *C. globularis* L., *C. limosa* L.

Shrubs with *Oxycoccus microcarpus* were recorded for this period. The quantity of green moss had reached the maximum value in the content of paleo plant formation. The reduction of peat decomposition and the increase of ash content were probably due to an increase in the duration and magnitude of floods. This time could be described as cool and wet, similar to the stage Fernau (the Alps) or Aktru (the Altais) [1].

Mixed herb plant formation was pervasive in the Narva peatland from the first half of the late Subatlantic period. However, the grass layer was reduced and participation of horsetail mezoeutrophical species was increased.

The majority of peatlands had a relatively young age in Kansk forest-steppe zone (from the end of the Atlantic to the beginning of subboreal period). The process of peat accumulation dated middle Subboreal time. More ancient peatlands were only preserved far from the major rivers, in places which were protected from erosion scours in the Boreal and Atlantic periods [15].

The rate of peat accumulation was 0.55 mm / year for the Narva peatland, which was slightly above the average for Kansk forest-steppe (0.44 mm / year) and the Krasnoyarsk forest-steppe (0.31 mm / year). The maximum rate of peat accumulation (0.72) was recorded at the bottom of the peat deposit, which was formed in the Late Subboreal and Early Subatlantic periods. According to the results of a peatland study dated with a smaller step, the maximum rate was observed from the second half of the Subboreal to the beginning of Subatlantic period (1.2 mm / year in the Terteg peatland (Kansk forest-steppe), and 1.6 mm / year in Kacha peatland (Krasnoyarsk forest-steppe) [6, 13].

Our study presented paleohydrological reconstructions from a eutrophycal peatland. Eutrophycal and ombrotrophic peatlands received their moisture inputs solely from precipitation. Such peatlands tend to be used as a source of the Holocene climate data. Long-term variations in peatland surface wetness were interpreted as changes in the regional climate. Magnan et al [10] concluded that the main paleohydrological trends from mid-to-late Holocene climate changes provided response of peatland ecosystems to climate variability.

In the end of Subboreal period we identified the transformation of wood-mash plant communities to herbal communities associated with changes in palaehidrological regime of the study area. Mithell et al.[9] concluded that the forest clearance resulted in increased evapotranspiration causing lowering of the water table on the bog and modification of the vegetation cover. This hypothesis had implications for the management of similar small raised bogs in karst-dominated landscapes (Finland and northern part of Yenisei Siberia). According to our data, the forest clearing did not occur in the study area.

The plant macrofossil and ash-content analysis showed changes in the species composition. McCaroll et al. [11] suggested that it could be difficult to differentiate between natural and anthropogenic patterns vegetation changes during the late Holocene. According to the results of our study, a high content of mineral elements in the peat cores from the last 300 years may be explained by a wide spread of agriculture in the study area.

In addition, pollen analysis will be obtained in the next period of our research project. That may show changes in the regional vegetation and assist in making a conclusion about the human activity in the study area.

4. Conclusion

The peatland formation started in the Early Subboreal period in the Mana River valley. All stages of the peatland formation were eutrophycal. The maximum value of the moisture conditions was 98 points. This result differed from the forest-steppe peatlands where the maximums peat moisture conditions were 92-94 points. The birch forest with sedge and hypnum mosses in its herbal layer grew in the second half of the Subboreal period. An active process of overgrowing and peat accumulation started in the shallow waters along the Mana River was due to the general decrease of the water level in the river. These processes developed under warm conditions of the Late Subboreal period.

The mixed herbal plant formation replaced the wood-marsh plant association at the start of the Middle Subatlantic period (1600 years BP). The reduction in the degree of peat decomposition and the increase in the ash content indicated a longer and large-scale floods. This stage could be described as cool and moist.

Отформатировано: Отступ: Первая строка: 0,5 см

The herb-wort phytocoenosis with inclusions of mezoeutrophycal plant species have been growing since the Late Subboreal period (950 years BP) with the high moisture conditions (peatland moisture condition) of the peatland.

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References

[1] Bezrukova E V, Vershinin K E, Letunova P P, Orlova L A, Krapivina S M, Chepinoga V V, Verhozina A V, Dudareva N V and Abzaeva A A 2004 *Botanicheskij zhurnal* **89** pp 221–232

[2] De Jong R, Blaauw M, Chambers F M and Christensen T R 2010 *Climate and peatlands* (Netherlands: Springer) pp 85–121

[3] Edvardsson J, Linderson H, Rundgren M and Hammarlund D 2012 *Journal of Quaternary Science* **27 (6)** pp 553–563

[4] Ellenberg H 1988 *Vegetation ecology of central Europe* (Cambridge: Cambridge University Press) pp 15–24

[5] Feurdean A N and Bennike O 2008 *Studia UBB Geologia* **53 (1)** pp 5–10

[6] Grenaderova A V 2005 *Dinamika bolot Krasnoyarskoj i Minusinskoj lesostepej: avtoref. diss. kand. geogr. nauk* (Barnaul) p 22

[7] Ignatov M S and Ignatova E A 2003 *Moss flora of the Middle European Russia* (Moscow: KMK Scientific Press Ltd.) pp 609–960

[8] Kac N Ya, Kac S V and Skobeeva E I 1977 Atlas rastitelnyh ostatkov v torfah (Moscow: Nedra) pp 372

[9] Mitchell E A, van Der Knaap W O, van Leeuwen J F, Buttler A, Warner B G and Gobat J M 2001 *The Holocene* **11(1)** pp 65–80

[10] Magnan G and Garneau M 2014 *Journal of Quaternary Science* **29(3)** pp 209–220

[11] McCarroll J, Chambers F M, Webb J C and Thom T 2017 *Quaternary International* **432 (A)** pp 39–47

[12] Ramenskij L G 1956 *Ekologicheskaya ocenka kormovyh ugodij po rastitel'nomu pokrovu* (Moscow: Gosudarstvennoe izdatelstvo selskohozyajstvennoj literatury) pp 57–67

[13] Rodionova A B, Grenaderova A V 2016 *Vestnik Krasnoyarskogo gosudarstvennogo agrarnogo universiteta* **4** pp 65–72

[14] Tyuremnov S N 1976 *Torfyanye mestorozhdeniya* (Moscow: Nedra) p 464

[15] Yamskih A F 1993 *Osadkonakoplenie i terrasoobrazovanie v rechnyh dolinah Yuzhnoj Sibiri* (Krasnoyarsk: KGPI) pp 117–128

[16] Kutenkov S A 2013 *Proceedings of the Karelian Scientific Center of the Russian Academy of Sciences* **6** pp 171–176

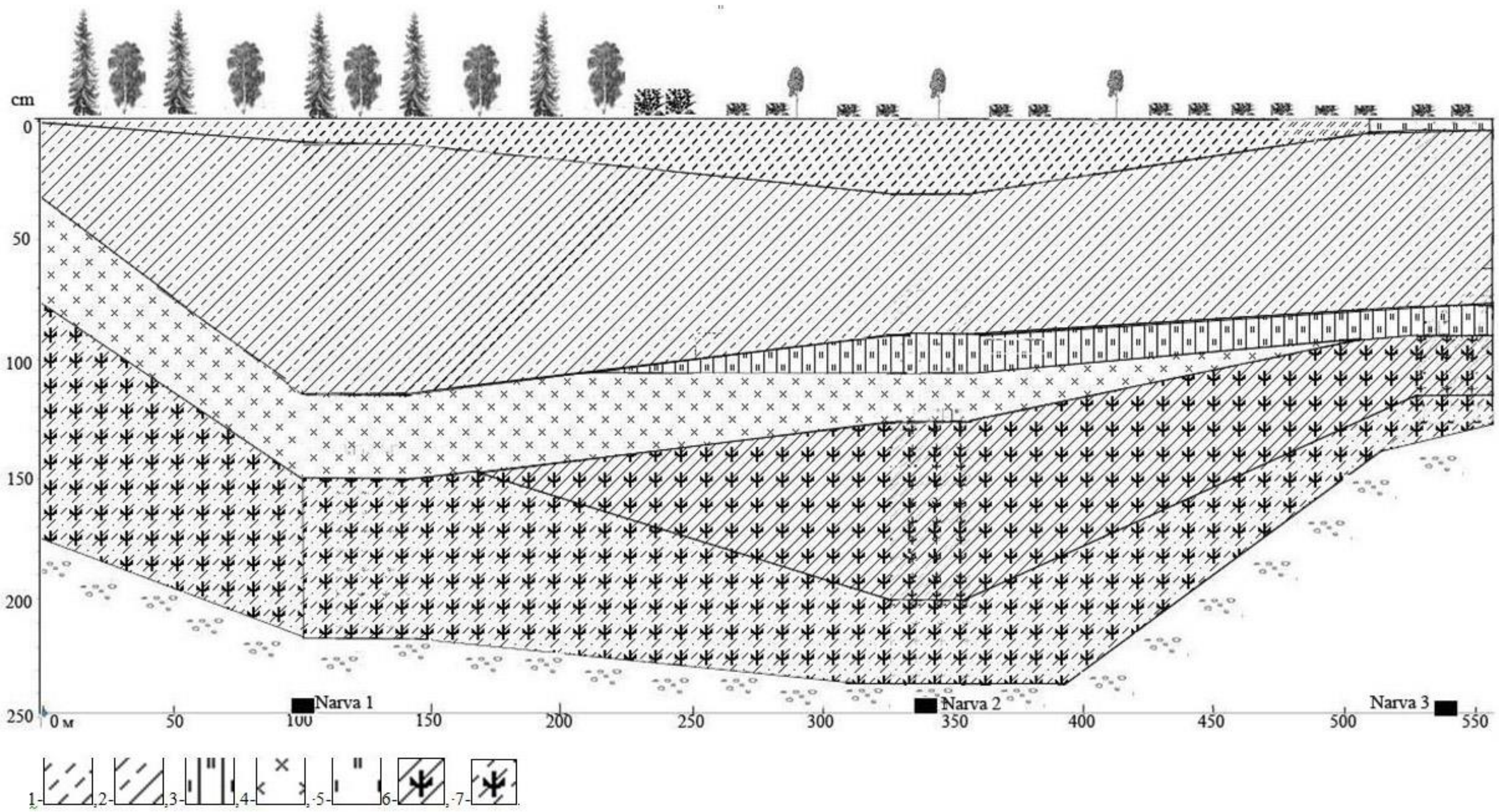

Figure 1. Schematic structure of the peatland deposits "Narva". Peat types: 1 – hypnum, 2 – sedge-hypnum, 3 – wood-herbal, 4 – equisetum, 5 – herbal, 6 – clay, 7 – sand clay.

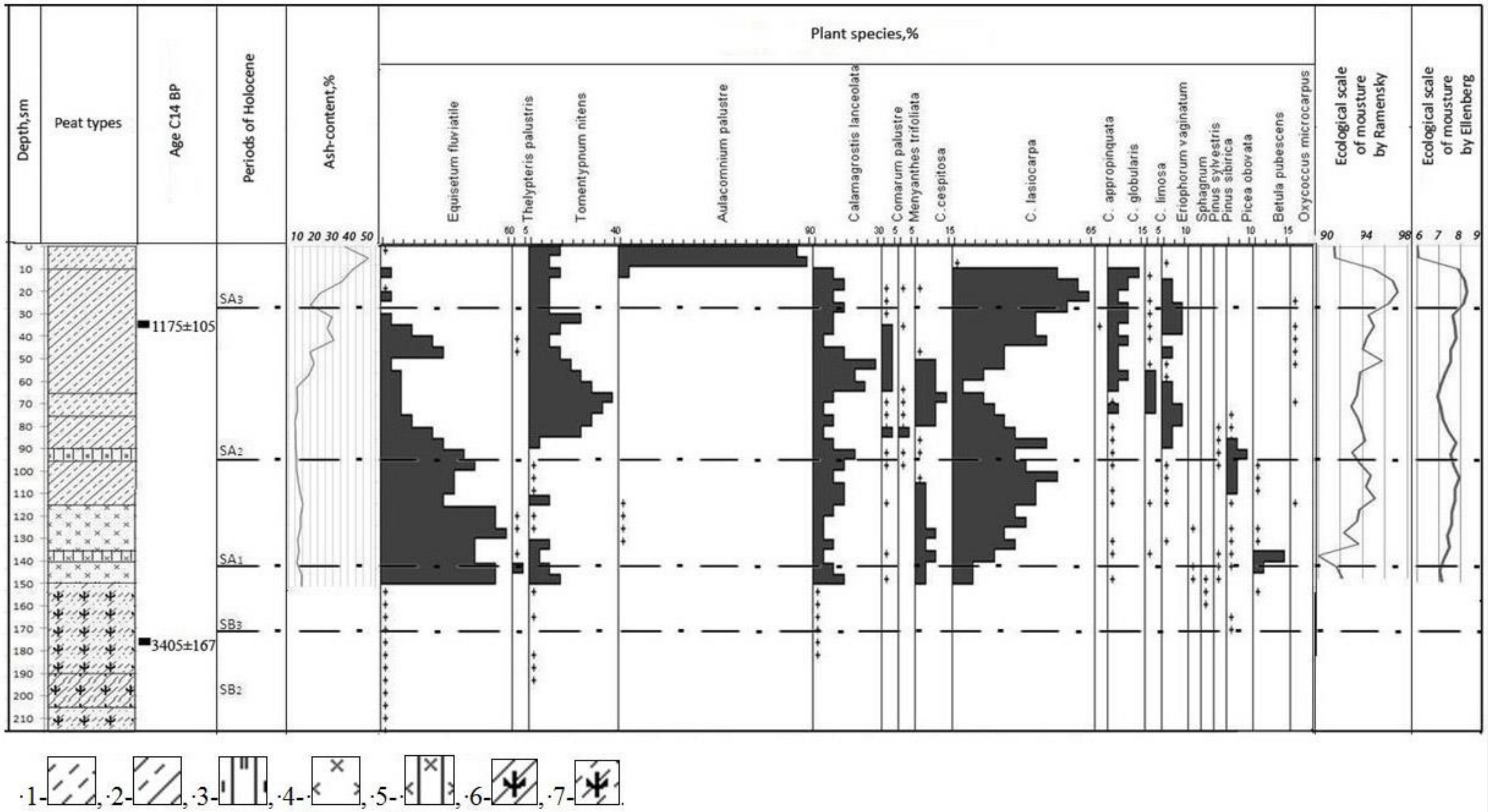

Figure 2. Peat types, ash content, plant species in peat samples and ecological scale of moisture. Peat types: 1 – hypnum, 2 – sedge-hypnum, 3 – wood-herbal, 4 – equisetum, 5 – wood-equisetum, 6 – clay , 7 – sand clay.